Engineered for 25 Years: Commercial Durability Proven in Elestor's Hydrogen–Iron Flow Battery Technology

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Abstract

Elestor's hydrogen–iron flow battery architecture is put to the test and evaluated under continuous, commercially relevant operating conditions to assess durability, performance stability, and lifetime potential. The system combines a hydrogen gas circuit with an aqueous iron-based electrolyte, enabling independent scaling of power and energy while relying on abundant, low-cost active materials (±2.8€/kWh, enable reaching 15€/kWh CAPEX and 0.02€/kWh Levelized Cost of Storage at system level).

An extended continuous cycling campaign demonstrates stable operation at practical current density, temperature, and voltage windows representative of real-world deployment. Measured performance remains stable and fully recoverable through standard conditioning procedures. The absence of structural or electrochemical failure under sustained operation provides a robust empirical basis for extrapolating operational lifetimes of 20–25 years under standard use profiles.

This work positions hydrogen–iron flow battery technology as a durable, scalable, and economically viable solution for long-duration energy storage.

1. Introduction

Long-duration energy storage systems must satisfy three simultaneous requirements: low capital expenditure, high round-trip efficiency, and multi-decade durability under continuous cycling. While numerous electrochemical systems demonstrate promising performance metrics at laboratory scale, comparatively few studies evaluate durability under realistic commercial operating conditions for extended periods sufficient to support lifetime extrapolation.

The hydrogen–iron flow battery architecture addresses scalability and cost constraints by decoupling power and energy capacity. Power is determined by the electrochemical cell stack, while energy capacity is defined by electrolyte volume. The electrochemical reaction couples hydrogen oxidation at the anode with the reversible iron redox couple at the cathode:

Cathode: $2Fe^{3+}_{(aq)} + 2e^- \rightarrow 2Fe^{2+}_{(aq)}$

Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Overall: $2Fe^{3+}_{(aq)} + H_2 \rightarrow 2Fe^{2+}_{(aq)} + 2H^+$

This chemistry relies on widely available materials and avoids reliance on constrained or volatile supply chains. However, low material cost alone does not guarantee economic competitiveness. For long-duration stationary storage, durability and lifetime stability are decisive cost drivers.

2. Experimental Approach

Testing is conducted on a large-format cell stack representative of commercial design principles. The active area reflects deployable system

dimensions. The architecture incorporates a hydrogen-fed anode, a stabilized proton-conducting membrane, a carbon-based cathode optimized for iron redox kinetics, and industrial-grade compression and current collection hardware.

The electrolyte consists of an aqueous iron salt solution in acidic medium, selected based on solubility, cost, safety, and durability considerations.

Durability validation is performed under commercially relevant operating conditions, including elevated temperature, continuous electrolyte circulation, constant current density, and cycling within a defined voltage window. Operation is automated and monitored through industrial control systems, with continuous logging of electrochemical and system parameters.

3. Continuous Cycling Performance

The system operates continuously for a sufficiently extended period to enable statistically robust evaluation of performance stability and lifetime projection. Cumulatively, tens of thousands charge–discharge cycles are completed under changing operating conditions representative of commercial deployment.

Round-trip energy efficiency consistently remains well above minimally viably targeted commercial levels (≥80% Energy Efficiency and ≥75% Round Trip Efficiency on system level). The selected operating window reflects practical deployment strategies that balance efficiency, operational stability, and system safety.

The electrochemical core maintains nominal performance throughout the validation campaign, demonstrating sustained operational stability under continuous cycling.

4. Operational Stability and Conditioning

Performance stability is maintained throughout extended operation. Periodic conditioning procedures restore the system to its initial performance envelope without structural intervention. These conditioning steps are fully compatible with standard operational practice in industrial energy systems.

Short rest intervals under controlled conditions positively influence internal resistance, suggesting dynamic equilibration phenomena within the membrane and electrode structures. Longer controlled shutdowns also correlate with stable subsequent operation.

No irreversible structural or electrochemical failure mechanisms are observed during the validation period.

5. Robustness Under Operational Disturbances

Durability assessment includes resilience to non-ideal events typical of industrial operation. During the validation campaign, the system experiences external interruptions unrelated to the electrochemical core.

In all cases, the performance or core components are not affected by these interruptions and/or restarts. This behavior demonstrates intrinsic chemical and electrochemical robustness and confirms the

suitability of the hydrogen–iron architecture for grid-scale deployment.

6. Secure Lifetime Extrapolation

Lifetime projection is grounded in empirical performance stability observed over an extended validation period under commercially relevant conditions. The absence of structural failure mechanisms, combined with stable efficiency and recoverable performance characteristics, supports conservative extrapolation to operational lifetimes of 20–25 years.

This extrapolation does not depend on assumptions regarding future material substitutions or technological breakthroughs. It is based solely on demonstrated stability under realistic operating parameters.

When normalized to expected annual operating profiles in grid-scale applications, the validated performance envelope securely supports multi-decade deployment.

7. Implications for Levelized Cost of Storage

Operational lifetime is a dominant factor in levelized cost of storage. A system that maintains commercially relevant efficiency while operating reliably over multiple decades fundamentally enhances economic competitiveness.

The hydrogen–iron architecture combines low-cost active materials (±2.80€/kWh), independent scaling of power and energy, demonstrated durability, and operational robustness. These characteristics underpin a storage solution capable of meeting long-duration energy storage requirements with predictable lifecycle economics (able to reach 15€/kWh CAPEX and 0.02€/kWh Levelized Cost of Storage at system level).

8. Conclusion

Extended continuous validation of a large-format hydrogen–iron flow battery cell stack under commercially relevant conditions demonstrates sustained operational stability and robust performance.

Efficiency remains within targeted commercial thresholds (≥80% Energy Efficiency and ≥75% Round Trip Efficiency on system level). The electrochemical core maintains structural integrity and functional stability under continuous cycling and operational disturbances.

The empirical durability record provides a secure foundation for extrapolating system lifetime to 20–25 years in grid-scale applications. The hydrogen–iron chemistry therefore combines economic viability with demonstrated long-term stability, positioning it as a credible and durable solution for long-duration stationary energy storage.